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Princeton University.
Presented by
School of Fire for Field Artillery.

OPTICS
of
Fire Control Instruments

Document No. 4a
OCTOBER, 1918

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SCHOOL OF FIRE FOR FIELD ARTILLERY

Fort Sill, Oklahoma,
October, 1918.

OPTICS OF FIRE CONTROL INSTRUMENTS.

Document No. 4a

ELEMENTARY OPTICS.

1. LIGHT AND VISION.

Light is that agent which produces the sensation of vision by its action upon the retina of the eye. By means of it we see objects at some distance from us. Some of these objects are self luminous or radiate light from themselves to our eyes and can therefore be seen in a dark room, for example, a lighted match, glowworm, or incandescent lamp. The sun and most stars are also self luminous.

In general, however, objects seen by us are not self luminous. They do not emit light themselves but are seen by means of the light from some other luminous body, which shines on them and is reflected by them into our eyes. Examples of such objects are books, stones, trees, hills, the moon, etc. These non-luminous objects would be invisible if not illuminated. The degree of their visibility depends upon the amount of light coming from them into our eyes. This in turn will depend first upon how much light is reflected by the object and secondly how far the object is from the eye. The farther an object is from the eye, the fewer are the rays of light which will enter the eye.

When light falls on a body, part of it is reflected, and part absorbed by the body and transformed into heat. In some cases part of the light is transmitted thru the body. Bodies which do not permit light to pass on thru them are termed opaque.

There are a few transparent bodies such as air, water, glass, and quartz which permit light rays to pass thru them without being scattered in many directions. A body which, like ground glass, permits light to pass thru it but scatters the rays in all directions is termed translucent. Objects may be seen thru transparent bodies but not thru translucent bodies.

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2. RAYS.

In order to understand the action of mirrors, lenses, and prisms upon light, it is convenient to think of the light as consisting of a very large number of individual "rays", and then describe what happens to one or two of these individual rays. A single ray is a very minute quantity of light—so small that the path traversed by it may be represented by a line. For instance, the candle in Figure 1 radiates light in all directions. We can represent this fact by drawing radial lines from the flame in all directions. These lines portray the paths traversed by different rays of light. A number of these rays grouped together are called a "beam" or "pencil" of light. S_1 is an opaque screen with a hole in it. Thru this aperture pass a number of rays and we have a beam of light on the right of the screen. Such a beam of light is continually widening as it moves away from its source and the farther away it gets, the weaker is its illuminating power. On the other hand, a ray is so small that its path never widens so much as to require more than a single line to represent it..

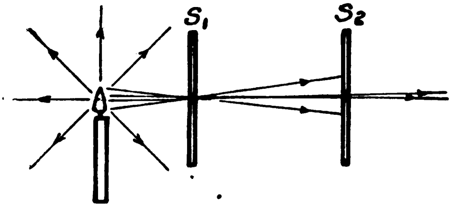


Fig. 1

The rays of a beam emitted from any single point in the candle flame are called divergent rays, because they continually diverge or separate from each other. A beam of light whose rays are traversing paths leading to a single point is said to be a convergent beam of light. By using another screen at S_2 we can still further reduce the number of rays passing on to the right. Note that these rays come from practically a single point of the flame and traverse nearly parallel paths. On account of their small divergence, they may be used as parallel rays. All rays of light which come from a distant object of moderate size and enter the pupil of the eye without having passed thru a lens are so nearly parallel that they may be considered as truly parallel in the discussions of this pamphlet.

Light rays travel along straight lines. They may change direction when reflected but their paths are straight in the new directions. Sun beams passing thru small chinks in the shutter of a dark room or thru broken clouds appear to travel in straight lines. We, therefore, assume that objects seen are in the direction from which the rays come to our eyes—that is, we do not see things around corners. The patterns of shadows indicate that light rays which just graze the edge of opaque bodies continue in the same straight paths. However, the assumption that light travels in straight lines is not strictly true. When light passes thru very small openings or is obstructed by very fine particles, there is some bending around the edges. This phenomenon is called diffraction. Many interesting effects are due to diffraction—for example, halos around the moon; streaks which are observed radiating from an electric light when seen thru a fine mesh screen, or a fog, or the eyelashes of one's partially closed eyes.

3. REFLECTION.

All surfaces reflect light to a greater or less degree. A purely black surface would reflect none at all. White light is very complex in nature consisting of all the different colors. A white surface, therefore, is one which reflects all colors of light and in so doing scatters it diffusedly in all directions. A colored surface is one which, illuminated with white light, reflects best its particular color of light and absorbs the other colors to a great extent—e. g. a red rose appears red because the light it reflects to the eye is predominately red in color.

Polished surfaces behave quite differently. If highly polished they reflect nearly all the light which strikes them and they do not scatter it but reflect it in certain definite directions according to the law of reflection. In Figure 2, MM represents a mirror; A, a source of light or an illuminated object; ADE and $A D'E'$, the paths of any two rays from A which are reflected by the mirror. DN and $D'N'$ are the normals (i. e., perpendicular lines) to the mirrored surface at the points where the rays strike the mirror. AD and AD' are called incident rays, DE and $D'E'$ reflected rays. The angles i and i' are angles of incidence and the angles r and r' are angles of reflection. The law of reflection states the well known fact that the angle of reflection is always equal to the angle of incidence and that the incident ray, the normal at the point of incidence and the reflected ray all lie in the same plane. This law tells us in what direction the rays AD and AD' will proceed after reflection. DE and $D'E'$ are drawn to comply with this law. If the eye of an observer is at E, it will receive the ray DE; if at E', the ray $D'E'$. In both places the ray received will seem to have come from the same point A′, behind the mirror. Such a point is called the "image" of A. It is the point from which all reflected rays appear to have come. $AD''E''$ is a third ray drawn to illustrate this fact. It can be easily shown from the above law that A' is at the same distance behind the mirror as A is in front of it—i. e., $AF=FA'$. The image of any object in a plane mirror is located as far behind the mirror as the object is in front of it. Such images are known as "virtual" images (in contradistinction to "real" images) since the light rays only appear to have come from them and have never passed thru them. The above case is typical of all cases of reflection from plane mirrors and is in accord with what we are accustomed to in our daily use of mirrors.

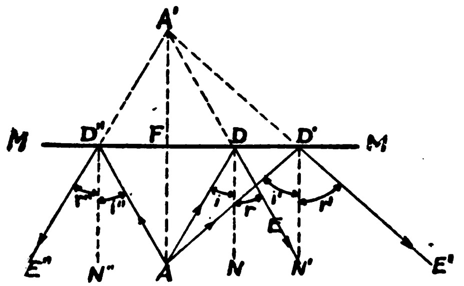


Fig. 2

4. REFRACTION.

Whenever light passes obliquely from one medium into a different medium the direction of its path is changed. This deviation is known as refraction and is due to the fact that light travels more slowly in dense media than in rare media.

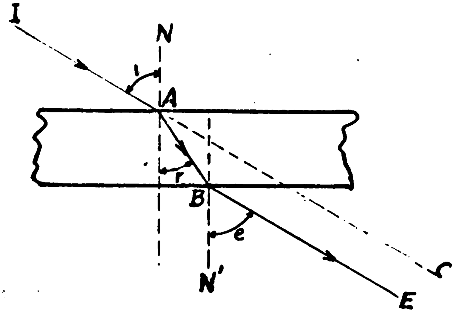


Fig. 3

Figure 3 illustrates a typical case of refraction. In it a ray of light is represented as passing thru a piece of plate glass. *IA* is the incident ray, *AB* the refracted ray, and *BE* the emergent ray. *AN* and *BN'* are normals to the surfaces between the air and glass at the points of incidence and emergence respectively. The angle *i* is called the angle of incidence; *r*, the angle of refraction; and *e*, the angle of emergence. On passing from air into glass the ray of light is bent toward the normal—i. e., *r* is less than *i*, and on emerging from the glass into the air again the ray is bent away from the normal by the same amount. In passing from a rarer to a denser medium light is always bent toward the normal, and vice versa. In this particular case, since the surface at *B* is parallel to the surface at *A*, the emergent ray is parallel to the incident ray. The only effect of the piece of plate glass on the path of the light is to displace it—not to change its direction. *AC* is the path the ray would traverse if the glass were not present.

A ray of light incident upon the glass along the line from *N* to *A* normal to the surface would pass on thru the glass in the same direction. Although it moves more slowly thru the glass, it is not bent. Only rays of light which meet the surface of the glass obliquely will be changed in direction.

5. PRISMS.

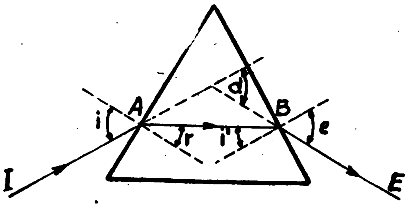


Fig. 4

In figure 4 is shown the cross section of a typical glass prism. *IABE* is the path of a ray passing thru the prism. *IA* is the incident ray, *AB* the refracted ray, and *BE* the emergent ray. According to our law of refraction, the angle *r* is less than *i*, and the angle *e* greater than *i'*. In this case of refraction the emergent ray is not parallel to the incident ray but is in a direction making an angle *d* with the latter called the angle of deviation. Rays of light passing thru a prism are deviated or bent toward the thicker part of the prism. Furthermore, rays of blue light are bent more than those of red light. Whence, white light in passing thru a prism is separated into its different colors giving the familiar "rainbow" effect, or spectrum.

6. TOTAL INTERNAL REFLECTION.

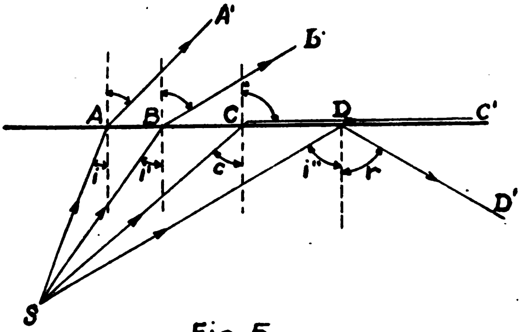
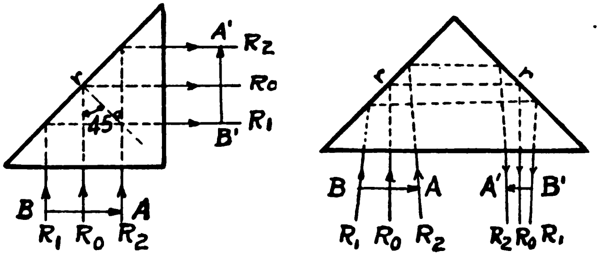


Fig. 5

Even the best polished surfaces do not reflect all the light incident upon them. There is, however, a case of reflection in which the light, incident upon a surface is totally reflected. In Figure 5, consider S to be a small electric lamp below the surface of water. SA, SB, SC and SD are rays from S incident upon the surface at increasing angles of incidence. AA' is the path taken by the ray SA on emerging into the air being bent away from the normal at A. BB' is also bent away from the normal at B but has a direction more nearly parallel to the surface since its angle of emergence is greater than that of SAA'. As the angle of incidence increases, there appears a certain critical angle of incidence illustrated in the ray SCC'. This ray on emerging from the water has been bent so far from the normal as to actually skim along the surface of the water as indicated. Such an angle of incidence as c is called the critical angle and its value differs for different substances—for water into air about 48°, for crown glass into air about 42°. The ray SDD' illustrates what happens in the case when the angle of incidence is greater than the critical angle—i .e., i'' is greater than c. The ray cannot of course emerge into the air. Instead it is totally reflected back into the water. Because this reflection takes place always on the interior surfaces of the denser media it is called total internal reflection. None of the light can pass thru the surface if the angle of incidence is greater than the critical angle of the substance concerned.

7. TOTALLY REFLECTING PRISMS.

The use of the above principle is illustrated in figure 6 in which two



Case (a) Case (b)

Fig. 6

forms of totally reflecting prisms are shown. These prisms are cut and polished (but not silvered) in approximately the shape of a 45° right angled prism. Consequently, such incident rays as R_0 along the normal meet the internal surfaces, r, in angles of incidence approximately equal to 45°. Since the critical angle for the glass of which these prisms are made is about 42°, all rays approximately parallel to R_0 are totally internally reflected at the surfaces marked r. If all the rays are parallel to R_0 as shown in case (a), they emerge from the prism still parallel and have each been turned thru an angle of 90°. In addition their relative position has been reversed. R_1 enters the prism on the left of R_0 but emerges on the right. In case (b) in which a Porro prism is shown we have a double internal reflection. R_0 is bent thru an angle of 180° and goes back into the same direction from which it came. R_1 and R_2 are reversed at the first reflection and again at the second. Consequently, they emerge in the same order as they entered the prism, R_1 on the left and R_2 on the right of R_0. However, if the incident rays come from an object, *AB*, the reflected rays will show this object in the position *A'B'*, or reversed. In this case the incident rays are also shown to be converging toward R_0. This convergence continues during the passage thru the prism and after emergence, the prism having no effect upon the convergence.

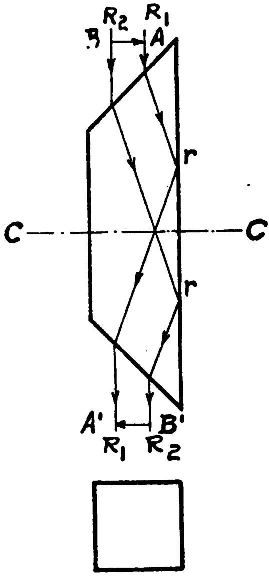


Fig. 7

In Figure 7 is shown another type of totally reflecting prism which is used in the panoramic sight. This prism is cut as shown and has a rectangular cross section. The rays are totally reflected from the surface r since their angles of incidence upon it are obviously greater than 45°. They are inverted in passing thru this prism—i. e. if *A* represents the top of an object and *B* the bottom, the object will appear upside down to an observer looking thru the prism, as shown by *A'B'*. In so doing it may be used to counteract the inversion produced by the lens system of a telescope.

8. THE PENTA PRISM.

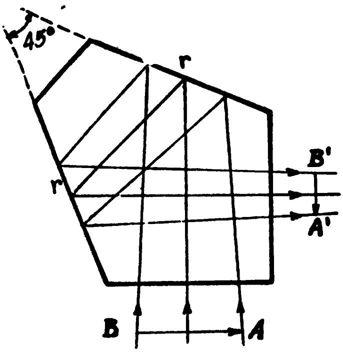


Fig. 8

This prism is illustrated in Figure 8. The faces marked *r* must be silvered in this prism since the rays do not meet these surfaces at angles of incidence greater than 42°. This type of prism is used in the range finder and its function is to deviate each of the rays thru an angle of 90°. As in the Porro prism, slightly convergent rays continue to converge in passing thru and emerging from this prism. Since there are two internal reflections the relative position of the rays is the same after emergence as in incidence. Objects viewed thru this prism appear neither reversed nor inverted. An important feature of this prism is the fact that rays passing thru it are always turned thru exactly 90°. In the three rays shown, each emerges in a direction at right angles to that of its incidence. The prism may be rotated slightly without changing this result since any effect at the first reflection is counterbalanced by an equal but opposite effect at the second reflection.

9. LENSES.

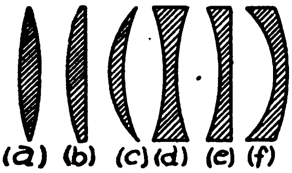


Fig. 9

A lens is a transparent body bounded by two spherical surfaces, or by one spherical and one plane surface. There are two general types of lenses, the convergent lens, thicker in the middle than at the edge and the divergent lens, thinner in the middle than at the edge. Figure 9 shows the different forms of these lenses—(a), (b), and (c) are convergent lenses; (d), (e), and (f) are divergent lenses. Practically no divergent lenses are now used in fire control instruments.

In Figure 10 the effect of a convex lens upon the paths of light rays is illustrated. The line CC′ which is drawn thru the centers of the two spherical surfaces is called the principal axis of the lens. A ray incident upon the lens along this line remains undeviated continuing in the same direction

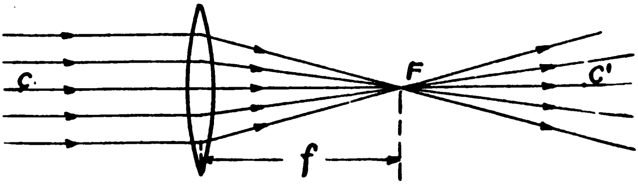


Fig. 10

after emerging from the lens. The other rays shown are parallel to the principal axis until they meet the lens. There they are deviated in the same manner as in the case of the prism shown in Figure 4, being bent toward the thicker part of the lens. Thus all the rays after emergence converge toward the principal axis where they meet in a common point called the principal focus of the lens. This is the simple action of a "burning glass" which converges both the heat and light rays from the sun to a point thus concentrating the heat to so great an extent as to produce ignition. The distance, *f*, from the center of the lens to the principal focus is called the focal length of the lens. Since blue light is refracted more than red light, it is brought to a focus more quickly. Whence the focal length of an ordinary lens for blue light is considerably shorter than that for red light.

Figure 11 shows the action of a typical divergent lens. Rays parallel to the principal axis are incident upon the lens. They are bent toward the thicker part of the lens and therefore diverge after emergence. They appear, however, to have come from a single point, *F*, behind the lens. This point is the principal focus of a divergent lens, and *f* represents the focal length, as before. Since rays of light do not actually converge at this point but only appear to emerge from it, it is called a "virtual" focus.

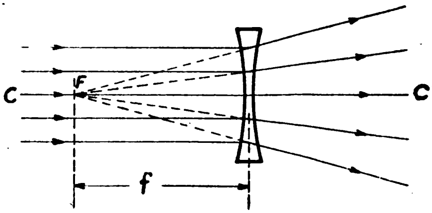


Fig. 11

10. IMAGES PRODUCED BY LENSES.

Rays from a single point which pass thru a lens either meet in another point after emergence or seem to have come from another point. If they actually do meet in a point after emergence that point, is termed a real image of the first. If they merely appear to have come from another point which they actually have not passed thru, that point is termed a virtual image of the first.

There is a simple method of locating the image of any object produced by a lens. By locating the images of a few points of an object we are able to locate the whole image of the object. The method is illustrated in Figure 12. *AB* represents an object, *L* the lens. Let us first determine the image

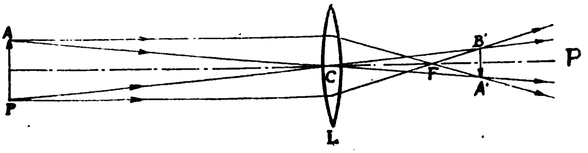


Fig. 12

of the point *A*. To do this draw the path of a ray from *A* thru C, the center of the lens. This ray passes thru the lens in such a position that the surface at emergence is very nearly parallel to the surface at incidence. Therefore according to what has been said in paragraph 4 there will be bending of the ray, only a shifting of it—negligible, if the lens is thin.

Its path after emergence may be drawn as simply a continuation of the line *AC*. Draw also a ray from *A* parallel to the principal axis. After emergence, it will pass thru *F*, the principal focus of the lens. Both of these rays meet after emergence at the point *A'* which is, therefore, the image of *A*. All rays from *A* meet at *A'* after passing thru the lens.

The figure shows a similar construction to locate the image, *B'*, of *B*. By drawing *A'B'* we have the complete image of *AB*. Each point of *AB* sends rays through the lens to a corresponding point on *A'B'*. An observer in the region *P* would receive rays originally from *AB* but appearing to him to have come from *A'B'*. The image is diminished in size, real, and both inverted and reversed—i. e., up side down and reversed right for left.

If *AB* were a pin and another smaller pin were placed at *A'B'*, they would appear to coincide to an observer at P.

11. SIMPLE MAGNIFYING GLASS OR EYE-PIECE.

This consists of a convergent lens so placed as to have the object observed nearer to the lens than the principal focus. The effect of this arrangement is shown in Figure 13. The lens is placed so that *AB* is within its principal focus. As before, two rays are drawn from *A* and *B* respectively—one thru the center of the lens and on, the other parallel to the principal axis and then thru the principal focus. After emergence, the two rays from *A* diverge but appear to an observer to have come from a single point, *A'* behind the lens. Similarly *B'* is found to be the image of *B*. An eye anywhere to the right of the lens would receive rays originally from *AB* but apparently from *A'B'*. The image *A'B'* is magnified, erect, and virtual.

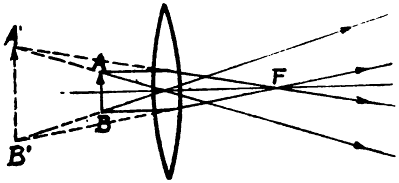


Fig. 13,.

In the use of a simple magnifying glass or eye-piece, the eye of the observer should be held close to the center of the glass. This has two effects. First, only rays which pass thru the center of the glass can enter the eye. Secondly, in this position more rays of light which pass thru the center of the lens can enter the eye and consequently the field of view is larger. Objects looked at thru the center of the lens only are clearest and best defined. (See next paragraph).

12. DEFECTS IN THE IMAGES OF LENSES.

There are several defects in ordinary lenses which tend to make images produced by them blurred and indistinct. The two most important ones are termed spherical aberration and chromatic aberration.

Spherical aberration is due to the sphericity of the surfaces of the lens. Actually rays from a single point which pass thru the edges of a lens do not form an image at the same point as the rays which pass thru the center of the lens. In other words, the image of each point consists of a number of different points and is a blur. This blurring due to spherical aberration is avoided to a great extent by the proper design of lens system and by using only the central portions of lenses, not the edges.

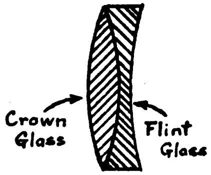


Fig. 14.

Chromatic aberration is due to the fact that rays of different colors do not come to a focus at the same point. Consequently, an object of various colors would have a blurred image. This defect can be almost wholly avoided by constructing lenses of both crown and flint glass so that the chromatic aberration due to the crown glass is counteracted by that due to the flint glass. Such lenses are called achromatic lenses. All colors are brought to the same focus by them. A convergent achromatic lens is shown in Figure 14.

13. THE SIMPLE TELESCOPE.

The optical system of a simple telescope consists of two parts—an objective lens and an eye piece. In Figure 15, the optical system of such a telescope and its action on the rays of light are shown. *O* represents the objective lens, a convergent lens of considerable focal length. *E* is the eye piece, also a convergent lens but of short focal length. The two lenses are so placed with respect to one another that *F* is the principal focus for both of them—i. e., they are a distance apart equal to the sum of their focal lengths. R_1, R_0, and R_2 represent three typical rays from the top of an object observed thru the telescope, say the point *A*. They will of course be very nearly parallel to one another since they come from a single point some distance away. Therefore after passing thru the lens, O, they will converge to a point very near and to the right of the principal focus, *F*. Consequently, the whole image of the object observed, *A′B′*, will be within the principal focus, *F*, of the eye-piece, *E*. Thus the eye-piece, *E*, will form a magnified image, *A″B″*, of *A′B′*. The typical action of each of these lenses is shown separately in Figures 12 and 13 respectively. The function of the objective lens is to bring the object near enough to be magnified, as it were. To do this it forms a real image of the object inside the focal length of the eye-piece. The function of the eye-piece is performed in magnifying the real image produced by the objective lens. Practically all the magnification is obtained from the action of the eye-piece.

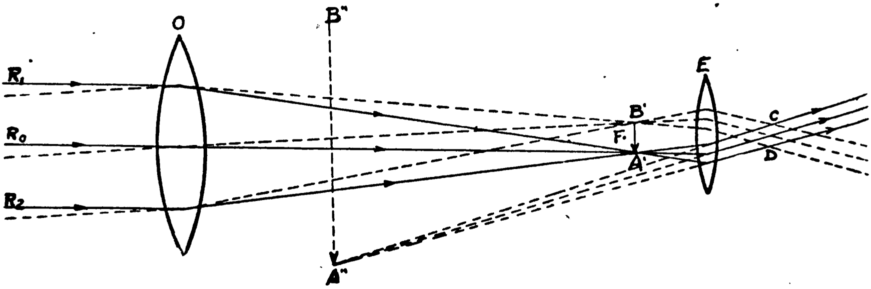


Fig. 15

The four important properties of all good telescopes are magnification (or power), illumination, field, and definition. We shall discuss the factors which determine these separately.

14. MAGNIFICATION.

Figure 16 depicts the magnifying effect of the above telescope. Figures (a) and (b) are drawn on very different scales. In (a) is shown the object observed, *AB*, and the position of the observer's eye, *P*, when no telescope is used. If *AB* represents a six-foot man at a distance of 2000 yards, then a ray of light from the man's head entering the eye, *P*, would make an angle of 1 mil with a similar ray from his feet. In (b) is shown the real image, *A'B'*, formed by the objective lens the focal length of which is assumed to be 10 inches. In this case *A'B'* would be approximately 0.01 of an inch in height. The virtual image *A"B"* of *A'B'* is also shown assuming the focal length of the eye-piece to be 1 inch. The virtual image would be approximately 0.1 of an inch in height and is located at about 10 inches from the eye at *P*. Whence a ray from *A"* and one from *B"* entering the eye would make an angle of about 10 mils. Since *A"* and *B"* are the points from which the rays, originally from *A* and *B* respectively, appear to have come, the image seen by the observer will appear to be about ten times larger than the actual object. The magnification or power of the telescope is said to be ten. Note that in the above example the focal length of the objective lens is just ten times that of the eye-piece. In general, the magnification of a telescope is equal to the number of times longer the focal length of the objective lens is than the focal length of the eye-piece.

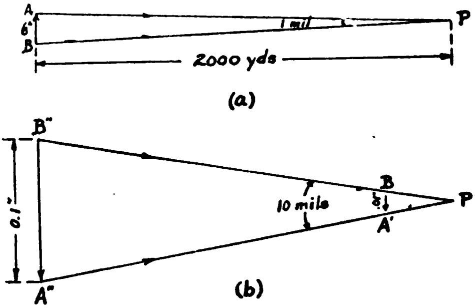


Fig. 16

15. ILLUMINATION.

By the illumination of a telescope we mean the relative amount of light which comes into our eye from the image. This image must be brightly illuminated in order to be clearly visible to the eye. And the larger the image is, or the greater the magnification, the greater must be the number of rays converged to form the image. The number of rays which can be converged by the objective lens depends obviously upon its size or effective diameter. Consider Figure 15 again. Telescopes are usually so designed that nearly all rays which enter the objective lens from a distant object also pass thru the eye-piece emerging in a circular beam of minimum diameter at *CD*. At this position the rays come closest together and therefore this is the place where the pupil of the eye should be so as to receive all the light which emerges from the eye-piece.

Furthermore, the diameter of the emergent beam at *CD* should be exactly that of the pupil of the eye for maximum efficiency. This would mean that all light entered the eye which the iris would accomodate. If the diameter at *CD* is less than that of the pupil of the eye, the full capacity of the eye for light cannot be utilized. If the diameter at *CD* is greater than that of the pupil of the eye, some light could not enter the eye, leading to poor illumination. The maximum diameter found useful in field artillery glasses is about 0.2 of an inch. Since the diameter of the emergent pencil is as many times smaller than that of the objective lens as the power or magnification of the instrument, it follows at once that in order to obtain an emergent pencil 0.2 of an inch in diameter, the magnification will be five times for a one inch objective lens, ten times for a two inch, and so on. In other words, for an objective lens of given diameter there is a limited range of magnification in order to obtain efficient illumination. Night glasses should have large objectives and may have large emergent beams also since the pupil of the eye is large. Glasses for use in strong daylight only should have small emergent pencils and therefore may have smaller objective lenses.

We have assumed in the above discussion that all rays which enter the objective lens pass thru the telescope. This is never true. Some of the entering rays are absorbed by the glass or cement used between lenses, and some more are reflected back. American made glass has never equalled that made in France and Germany in clarity and transparency. Reflection of some light always takes place at all surfaces between glass and air, particularly if these surfaces are the least bit dirty, dusty, or scratched. Any light lost in transmission in either of these two ways means a reduction in illumination. Consequently the clearer the glass, and the fewer the lenses or glass surfaces, the better the illumination secured.

16. FIELD.

By the field of view of a telescope is meant the angle that may be viewed simultaneously with it. The normal field of the unaided eye for distinct vision is about 45° or 800 mils. If the magnification of a telescope were one and it were perfect, its field of view would equal that of the unaided eye. In practice, however, this is not usually accomplished. A telescope with a magnification of four does not have a field greater than one-fourth of 800, or 200 mils, and will usually have a field less than this. The field of a telescope should be nearly equal to 800 mils divided by its magnifying power. Consequently, glasses of high magnification have perforce small fields. Some means must be provided such instruments to steady them, for any slight movement will cause the images of the objects under observation to move also and with a rapidity magnified by as many times as the magnification of the instrument. These images, if not moved entirely out of the field of view, will appear blurred and indistinct unless the instrument is held still.

17. DEFINITION.

By the definition of a telescope is meant the relative distinctness with which the edges and details of an object may be viewed. This depends chiefly upon the following three conditions.

First, the spherical aberration of the lenses must be avoided in so far as possible. In objective lenses this is accomplished in the design of the lens. They are usually plano-convex achromatic lenses with the light incident first on the convex surface. Furthermore, only a small portion of a relatively flat lens is used. Eye-pieces, however, usually consist of a system of two lenses so designed as to eliminate to a high degree any distortion or blurring of the image due to spherical aberration.

The Ramsden eye-piece consists of two equal plano-convex lenses with their curved faces turned toward each other and the distance between them equal to two thirds the focal length of one of them.

Secondly, the effects due to chromatic aberration must be eliminated. This is done by the use of achromatic lenses or systems of them.

Thirdly, the resolving power of a telescope is a very important factor. This is frequently confused with magnifying power but is of an entirely different nature. There is a certain limit beyond which there is nothing to be gained by increasing the magnification of a telescope. The image may become larger but no new details will appear. It is just like pulling out an elastic sheet on which a picture has been painted. The picture becomes larger but nothing new is revealed. The amount of detail which can be revealed by a telescope is measured by its resolving power.

18. RESOLVING POWER.

By the resolving power of a telescope is meant the smallest distance which may separate two points and yet permit them to be clearly separated in the image formed by the telescope. The fact that two points closer together are not resolved in the image is due to the phenomenon called diffraction. The nature of diffraction is closely linked with the wave theory of light and will not be discussed in this pamphlet. This critical distance between two points that can just be resolved by a telescope is usually given in angular measure—i. e., the angle between the two rays from the points which meet at the telescope. This angular distance between them does not depend upon their distances from the telescope. For any telescope the resolving power in seconds is approximately equal to the number of times the effective (or used) diameter of the objective lens in inches is contained in five—i. e. the larger the objective lens, the better the resolving power of the instrument. The resolving power of the average normal eye is approximately one minute, or 60 seconds. If, for instance, the diameter of the objective lens of a telescope is one inch, its resolving power is about five seconds, i. e., two points separated by an angular distance of 5 seconds will be resolved by it. If the magnification is 12 times, then this angular distance will be magnified 12 times and the two points will seem to be 60 seconds apart to the eye of the observer. The normal eye can separate these two points. If the magnification of this same instrument were only ten times the eye might not be able to see all the details resolved by the telescope and if the magnification were 15 times, no more detail would be afforded than with a magnification of 12 times. In the latter case the points just resolved would be stretched further apart but no fresh detail would be revealed. In order to obtain more detail, it would be necessary to increase the diameter of the objective lens. In telescopes of low power such as those described in this pamphlet, the resolving power is made high enough for the corresponding magnification obtained.

19. PRISMATIC TELESCOPES.

The telescope shown in Figure 15 is known as an astronomical telescope. It cannot be used conveniently to observe terrestrial objects as the images formed by it are both reversed and inverted. An object viewed thru it would appear both reversed right and left and upside down. To correct this an "erecting" system is used. In fire control instruments this erecting system usually consists of totally reflecting prisms. Figure 17 shows the simplest prismatic system.

The two prisms, P_1 and P_2, are so oriented as to be at right angles to each other. R_0 represents a ray from the center, R_1 from the foot, and R_2 from the left of the same object. The box, x, and arrows, AB and AC are drawn to indicate the relative positions of these rays. After passing thru P_1, the ray R_1 has been inverted to the other side of R_0 while R_2 remains in the same relative position as before. After passing thru P_2, however, R_2 is reversed with respect to R_0 while R_1 remains unchanged. Thus P_1 inverts and P_2 reverses the rays so that an object view thru these prisms would appear upside down and reversed right or left. The arrows, $A'B'$ and $A'C'$, and the box x, may aid in showing this. By interposing this prism system between the objective lens of a telescope and the image formed by it, the inversion and reversion due to the lens are counteracted by the action of the prisms thus giving an erect and natural image. Furthermore, the use of prisms enables us to reduce the length of a telescope (since the ray is doubled back on its path), to obtain an increased stereoscopic effect (see paragraph 27), and finally to employ periscopic systems enabling the observer to secure some concealment and protection.

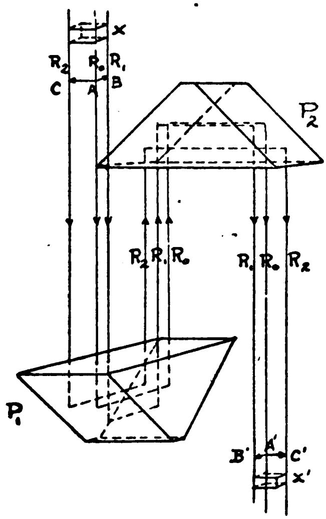


Fig. 17.

20. RETICULES.

Reticules with either cross-hairs or scales are used in all fire control instruments. The reticule is always placed in what is called the focal plane of the objective lens. It is in this plane that the real image formed by the objective lens is located. Consequently, the cross-hairs, or scale, are thus coincident with the real image of the objective lens and both will be magnified simultaneously by the eye-piece and will appear to the observer to be superimposed.

THE EYE.

21. DESCRIPTION.

The eye consists practically of a spherical chamber with a circular opening in the front; by means of a system of lenses the light entering this opening forms an image on the back of the chamber just as in the case of a photographic camera.

Figure 18 represents a section of the human eye. It is surrounded by a coating "*S*" called the sclerotic—the white of the eye. The front portion of this coating, "C", is transparent and is called the cornea. "L" is the crystalline lens which is attached to the walls of the eye by the ciliary muscle. This muscle can change the shape and optical power of the lens. In front of the lens is a diaphragm, "*I*", called the iris, which is colored. In the center of this diaphragm there is a circular aperture called the pupil. The space "*A*" between the lens and cornea is filled with a liquid containing a little salt in solution, called the aqueous humour. The space, "*V*", behind the lens is filled with a transparent jelly-like substance termed vitreous humour.

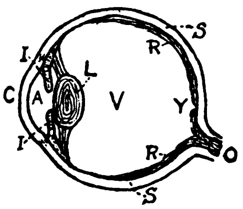


Fig. 18

After passing thru the cornea, aqueous humour, lens, and vitreous humour the rays fall on the retina "*R*". The retina consists principally of a network of nerve fibres connected with the brain by the optic nerve, "*O*". In the retina directly behind the pupil is the "yellow spot", "*Y*", which has a depression in the center; here vision is most distinct. The point on the retina at which the optic nerve enters is not sensitive to light and is called the blind spot.

For an object to be seen clearly its image must fall on the middle of the yellow spot. Then two points can be distinguished when they subtend an angle of 1 minute at the eye—i. e. here the resolving power of the eye is 1 minute. The images of these two points will be 0.005 of a millimetre apart on the retina. Rays falling on the peripheral regions of the retina form blurred images, and the objects from which they come cannot be seen distinctly. The image formed on the retina is an inverted one but this causes no confusion since the impression it produces is always associated mentally with the upright position of things.

As light rays enter the eye, they are refracted mainly at three surfaces, the outer surface of the cornea and the two surfaces of the lens. Actually the lens itself consists of many layers of different density. The image finally formed on the retina is due to these many refractions. The normal eye suffers both from spherical and chromatic aberration.

22. ACCOMODATION AND DISTINCT VISION.

When looking at a distant object the normal eye is at rest—i. e., the ciliary muscle is relaxed. In this condition, the image of the distant object is clearly formed on the retina; the lens system of the eye brings parallel rays to a focus on the retina. When looking at a near object, however, such as a book, the ciliary muscle automatically contracts and shapes the lens so as to make its refracting power greater and thus bring the diverging rays from a near object to a focus on the retina. In this state the eye is subjected to a strain and suffers a certain amount of fatigue. Consequently, to rest the eye, look at distant objects but not intently—or close the eyes. The changing of the shape of the lens in order to observe objects at different distances is known as the accomodation of the eye. The range of accomodation is limited. The normal eye sees small objects most distinctly when they are at a distance of 10 or 12 inches from the eye. This distance is called the distance of distinct vision, because, if the object is nearer, an exertion is required to focus on it; and, if it is further away, although quite as distinct it is smaller and less detail can be seen.

23. SHORT SIGHT.

In myopia, or short sightedness the focal length of the eye is too short and parallel rays are brought to a focus in front of the retina. Consequently, distant objects cannot be seen distinctly. Near objects can be seen very well, but the distance of distinct vision is less (from 4 to 8 inches) than in the case of the normal eye. Consequently, the image on the retina is larger than in the case of a normal eye. Figure 19 illustrates the defect of short sightedness and how it is corrected by means of a divergent lens. *AB* represents an object about 10 inches from the eye. The image formed by the eye alone is shown in (1) as *A'B'* in front of the retina. In (2), the lens, *L*, causes the ray *A-L* to diverge along *P-K* while the ray *A-O* is refracted very little. Hence *A-L* meets *A-O* at *A'* on the retina at a greater distance behind the lens of the eye than without the aid of the divergent lens *L*. The focal length of the lens, *L*, is determined by the degree of short sightedness of the individual and secondly by whether the glasses are to be used for reading, or for seeing distant objects.

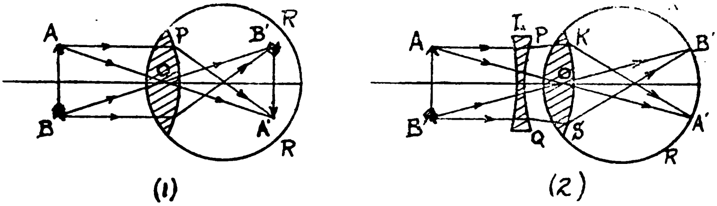


Fig. 19.

24. DIOPTERS.

The power of a spectacle lens is always measured in diopters and is obtained by dividing 100 by the focal length of the lens in centimeters. A + is prefixed to the result if the lens is convergent, a — if it is divergent.

25. LONG SIGHT.

In hypermetropia, or far sightedness, the focal length of the eye is too great, and, when the eye is relaxed, parallel rays are brought to a focus behind the retina instead of on it. By the act of accomodation the focus can be brought on to the retina in the case of distant objects and consequently they can be seen clearly. But even when the lens of the eye is curved as much as possible, the images of near objects still fall behind the retina and appear blurred. The distance of distinct vision is greater than that of the normal eye and the image formed is therefore smaller. Far sightedness is corrected in the same way as nearsightedness but by the use of a convergent instead of divergent spectacle lens.

26. ASTIGMATISM.

In astigmatism the focal length of the eye is different in two planes at right angles to each other. If on a card two sets of parallel lines are ruled at right angles to each other and the card is rotated so that the directions of the lines correspond with the above two planes, only one set of lines can be seen distinctly at once. If the other set is to be seen distinctly, the accomodation of the eye must be altered and the first set put out of focus. Astigmatism is due to the surfaces of the lens and the cornea, principally the latter, not being symmetrical about their axes. It is corrected by the use of cylindrical lenses or lenses having different refracting powers in two planes at right angles to each other.

27. BINOCULAR VISION.

When we look at a near object, the lines of vision of the two eyes have to converge towards it and an act of muscular accomodation must be made. The magnitude of this muscular exertion helps to give us an idea of the distance of the object—the greater the exertion, the nearer the object; the less the exertion, the farther the object. Our estimation of distance, however, is principally made in another way altogether. This second method depends upon the mental association of an optical effect with distance or perspective. The image formed on the retina of one eye is not exactly the same as the image formed on the retina of the other, because the object is observed by the two eyes from different standpoints. This difference is easily noticed when we look through a window and close first one eye and then the other; and the window frame appears to move relatively to the background. It is associated mentally with solidity, or depth. If the two images were exactly the same as in the case when we look at a picture, the images on the retinas of the two eyes would fuse together perfectly, and give us the sensation of flatness; the objects in the picture would not stand out in relief, or depth. The stereoscope is a simple application of this so called stereoscopic effect. In prism binoculars and scissors telescopes the stereoscopic effect is somewhat exaggerated giving a slightly more distinct impression of the relative distance of familiar objects from the observer.

FIRE CONTROL INSTRUMENTS.

28. THE BATTERY COMMANDER'S TELESCOPE—Model of 1905.

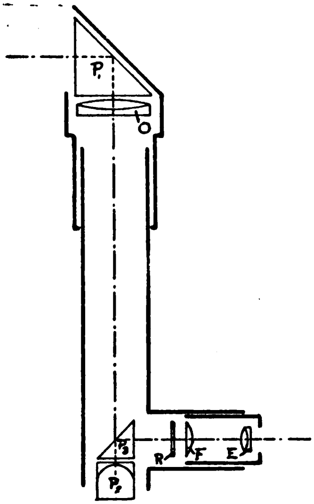


Fig. 20.

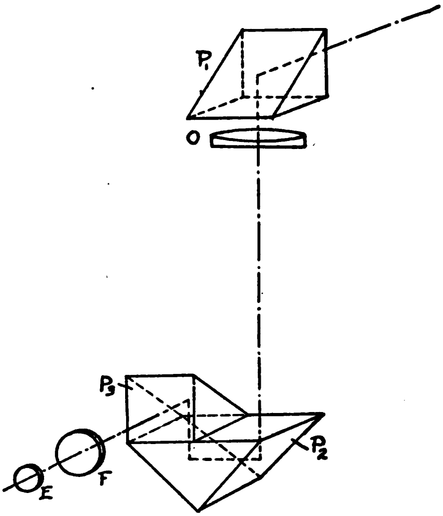


Fig. 21.

The optical system of this instrument is illustrated in Figures 20 and 21. The letters represent the same things in both figures. P_1 is the so-called objective prism. Its chief function is to reflect horizontal rays from objects observed vertically downward. By this means we are enabled to enjoy the advantages of concealment and protection afforded by a periscopic system. O is the objective lens and is an achromatic lens with an aperture 1.75 inches in diameter and a focal length of 11 inches. P_2 is a Porro prism. Its function is to counteract the reversion of the image produced by the objective lens. It only incidentally changes the direction of the rays by 180° and displaces them to the left. P_3 is another simple reflecting prism like P_1 thru which the rays pass immediately after passing thru P_2. This prism reflects the rays thru an angle of 90° thus returning them to their horizontal direction. By the action of P_1 and P_3 together the inversion produced by the objective lens is counteracted. *R* represents the position of the reticule, a thin plane of glass on which is marked the cross hairs and mil scales. The real image formed by the objective lens must be brought into exact coincidence with the plane of this reticule in order that there shall be no parallax between the scale and the image. To do this the objective prism and the objective lens are so mounted that they may be moved up and down thus lengthening or decreasing the distance between the objective lens and the reticule, *R*, so as to bring the image into coincidence with the latter.

The eye-piece is a modified Ramsden type and consists of two lenses, *F* the field lens, and *E* the eye lens. The field lens is a plano-convex lens of focal length 2.25 inches. The eye-lens is an achromatic plano-convex lens of focal length 2.125 inches. Their curved surfaces are turned toward each other. Together they act like a magnifying glass and form magnified images of the reticule and simultaneously of the real image formed by the objective lens. The eye-piece can be moved in and out so as to enable different observers to bring the magnified image of the reticule to their particular distance of distinct vision. This distance is quite different for different eyes. For the normal eye it is 10 to 12 inches.

29. PANORAMIC SIGHT—Model 1915.

The optical system of this instrument is similiar to that of the B. C. telescope but its prism system is quite different and much more delicate of adjustment. Figure 22 shows an objective prism, P_1, whose function is mainly to reflect the rays down the tube of the instrument. P_2 is the "rotating prism". It rotates thru only half the angle thru which the head is turned. In the position shown, its function is to counteract the inversion produced by the objective lens, (See par. 7). When the head of the instrument is turned thru 180°, this prism is rotated thru 90°. In this position, it does not affect the uprightness of the image produced, but reverses the right and left rays from the object viewed thus making the object appear to the observer to be in front of him instead of directly in rear as it actually is—i. e., the rotating prism actually seems to rotate the object viewed from a position in rear to a position directly in front. If the rotating head be turned so as to view an object on the right flank, then the rotating prism is turned thru 45° and thus counteracts the effect of the object viewed being on the right flank. Without the rotating prism, the whole landscape at the right flank would appear turned thru 90°—i. .e., on edge—due to the action of the prisms P_1 and P_3. It is this effect that the rotating prism counteracts. It counteracts the inversion produced by the objective lens for objects in front, and for all other positions of the object it so changes the relative positions of the rays as to make the object appear to the observer to be directly in front of him.

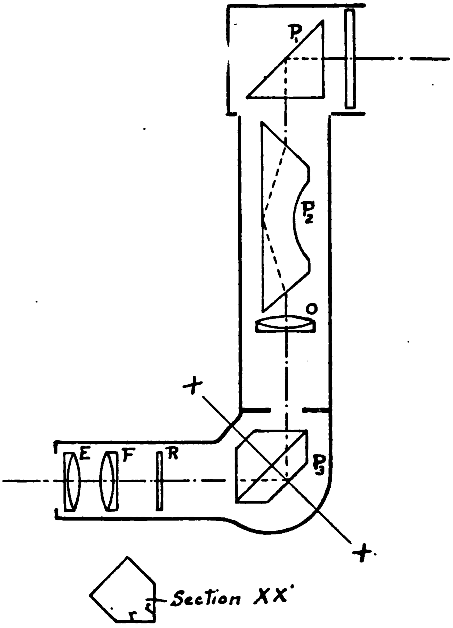


Fig. 22

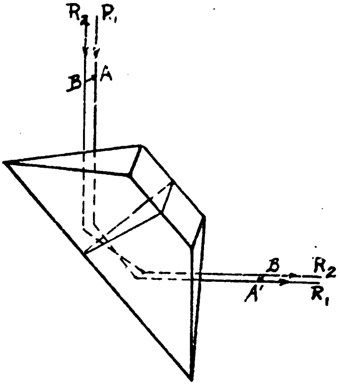


Fig. 23

The prism P_3 is not a simple 45° reflecting prism. Its shape is shown in the cross section XX'. In Figure 23 we have an illustration of the action of the two reflecting surfaces marked r, which are perpendicular to each other. The ray R_2 enters the prism to the right of R_1 and is reflected from one of the inclined surfaces to the other, emerging finally at the left of R_1. Thus, if the two rays come from an object AB, that object would appear reversed to an observer looking at it thru this prism, as shown by $A'B'$. The prism not only changes the direction of the rays by 90°, but also reverses them. In doing the latter it at all times counteracts the reversion produced by the objective lens. In conjunction with P_1 it counteracts the inversion produced by the same lens for objects viewed in rear of the observer.

The combined action of all three prisms is necessary to make objects viewed appear in their natural relative positions. The objective lens, O, field lens, F, and eye-lens, E, are all achromatic lenses. The reticule, R, is placed in the focal plane of the objective lens where the image is formed. In this instrument no adjustment is provided for changing the distance between the objective lens and the reticule. As a matter of fact, the images of all objects at a distance are formed in very nearly the same plane—so nearly that no adjusting device is necessary. The eye-piece is also fixed. Consequently, persons with abnormal eyesight may have some difficulty in seeing objects distinctly. The magnifying power is four times and the field of view 10°. The large field assists the gunner considerably in finding the aiming point readily.

30. THE AIMING CIRCLE.

This is the simplest of the fire-control measuring instruments. Like the others its telescope is of the prismatic type. The prism system consists of an objective prism reflecting the rays thru 90°, an erecting prism which counteracts the inversion produced by the objective lens and an "elbow" prism which reflects the light simultaneously thru a horizontal angle of 90° and a vertical angle of 45°. The combined action of the objective prism and the "elbow" prism counteracts the reversion produced by the objective lens. The telescope proper has an objective lens of focal length about 2.0 inches and diameter 0.5 inches. The small diameter of this lens leads to mediocre illumination and definition. The magnifying power is four times and field of view about 10°.

31. THE RANGE FINDER.

Figure 24 shows the principles underlying the construction and action of the Bausch and Lomb range finder. There are two telescopes having a common eye-piece, E, and objective lenses O_1 and O_2, called the left and right objectives respectively. An ocular prism system at P_3 is so designed as to reflect to the eye-piece only the lower half of the field of view of O_1, and the upper half of that of O_2. R represents the position of the focal plane

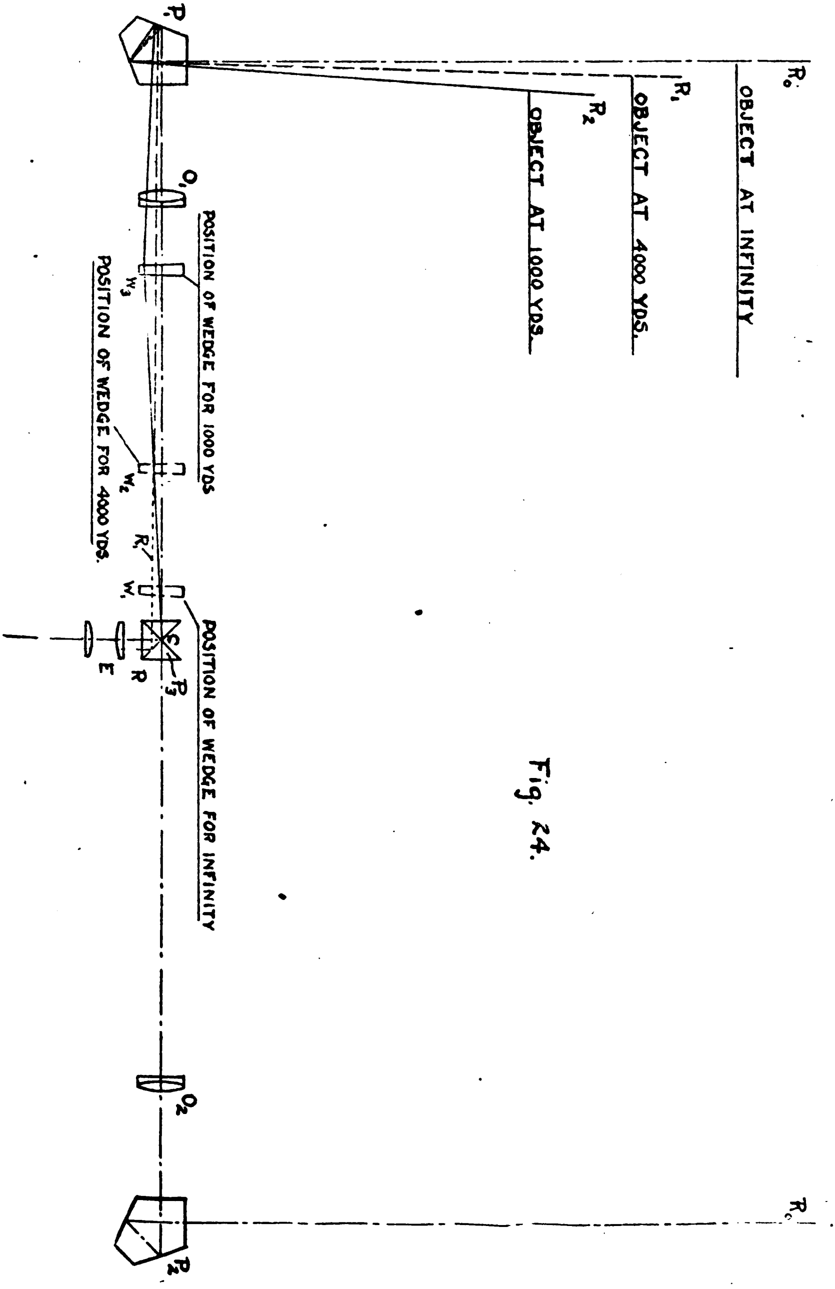

P₁
R₀
R₁
R₂
OBJECT AT INFINITY
OBJECT AT 4000 YDS.
OBJECT AT 1000 YDS.
O₁
POSITION OF WEDGE FOR 1000 YDS
W₃
POSITION OF WEDGE FOR 4000 YDS.
W₂
R₁'
W₁
POSITION OF WEDGE FOR INFINITY
P₃
R
E
O₂
P₂
R₀

Fig. 24.

which is common to both O_1 and O_2. Upon looking thru the eye-piece the observer sees in the lower half of the field of view an erect natural image formed by rays from O_1, and in the upper half, an inverted but not reversed image formed by the rays from O_2. The rays from O_1 originally enter the instrument via the penta prism P_1, those from O_2 thru P_2. (See Par. 8 for description of the penta prism.) The centers of these two penta prisms are exactly one meter apart. The dash and dot lines R_0, represent parallel rays entering the two penta prisms, or rays from the same point an infinite distance away, as, for example, a single point on the edge of the sun. These two rays will pass along the axis of the optical system and meet at the center, C, when the measuring wedge, W, is in the position W_1. As a matter of fact, W, even when in the position W_1, deviates the rays slightly. In order therefore to have the ray from the right objective meet the ray from the left objective at C, it is necessary to use a prism on the right side also to produce a corresponding deviation of the ray from the right. This prism is called the correction prism in actual instruments. The image of the point from which these two rays come would appear to the observer exactly in the center of the field of vision—i. e., the images in the uper and lower halves of the field of view would coincide. If the observer desires to see a church steeple, say 4,000 yards away, the inverted image of the steeple may be brought into the center of the field of view by turning the instrument so that rays from the steeple enter the right objective along the same path as before. Now, however, the image in the lower half will be displaced toward the right of the field of view for the path of the ray (illustrated by the dash line, R_1) meets the reflecting surface of the ocular prism not at the center, C, but to the right of it whence it is reflected into the eye-piece. The images would appear as shown in figure 25. This image may be brought to the center by moving the measuring wedge W from position

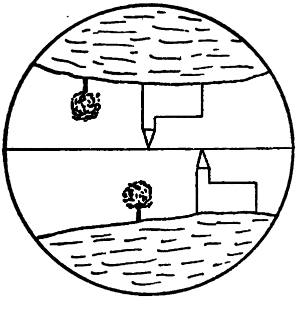


Fig. 25

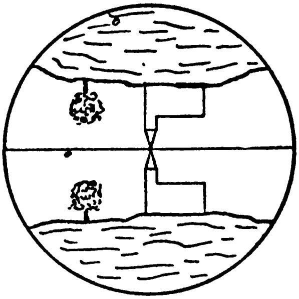


Fig. 26

W_1 to W_2. This measuring wedge is a simple prism (see Par. 5,) and deviates the ray R_1 so that it meets the ocular prism at the center C, when in the position W_2. The lateral movement of this prism necessary to bring the images into coincidence, as shown in Figure 26, is the means by which we can measure the distance to different points. Each position of the wedge corresponds to a certain definite range and will bring into coincidence the images of an object at that range. By connecting a spiral scale to the mechanism which moves the prism, the range to any object may be immediately read when the prism has been moved so as to bring the images into coincidence.

In Figure 24, R_2 (full line), shows the path of a ray from a tree 1000 yards distance.* In order to bring the images of this tree into coincidence in the center of the field the measuring wedge must be in the position of W_2.

This measuring wedge is a prism with a very small refracting angle, whence the deviation produced by it is very small. As may be readily seen, the angle between R_1 and R_2 is also very small. The small deviation produced by W furnishes a sensitive means of measuring such small angles. It is quite obvious that an optical system which is used for such minute measurements must be very delicately adjusted and, when once so adjusted, great care must be exercised not to disarrange even slightly any of its parts.

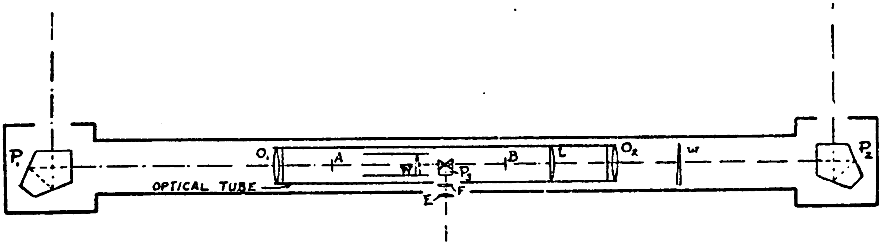


Fig 27.

Figure 27 shows the actual arrangement of the optical system in the Bausch and Lomb, 1 meter base artillery range finder. It consists of:

2 Windows (wedge-shaped);
2 Penta prisms; P_1, P_2
1 Correction wedge; w
2 Objective lenses; O_1, O_2
1 Correction lens; L
1 Measuring wedge; W
1 Ocular prism P_3
1 Field lens; F
1 Eye lens; E

These optical parts are embodied in a seamless steel tube covered with canvas and asbestos to minimize the effects of temperature. The eye piece is fastened to the center of the tube. The windows and penta prisms are mounted at the ends of the tube and the distance between the centers of the latter is 1 meter. The main objective lenses, correction lens, measuring wedge and ocular prism are mounted in an optical tube made out of a solid piece of hammered steel, repeatedly annealed until it is almost insensible to temperature changes. The correction wedge is located between the optical tube and the right penta prism.

The windows are wedge-shaped so that any lack of exactness in the right angle of the penta prisms may be counteracted by them. The manufacturer makes a final adjustment by rotating these windows which are then fixed in their place. If they later are moved or become loose the whole instrument is put out of adjustment.

The correction wedge is employed in order to offset the slight deviation produced in the left telescope by the measuring wedge in its infinity position and thus to enable us to bring the images of an infinite object into coincidence. It also affords a means of readjusting the optical system when it has been slightly disarranged. It consists of a simple wedge shaped prism which may be rotated thru an angle of 90°. The deviation produced by this prism varies as it is rotated. The effect of this is to move the inverted image in the upper half of the field of view to the right or left; and also up or down. To adjust the range finder it is best to sight at an object at a known distance. Set this distance off on the range scale by moving the measuring wedge. Then having adjusted the images so that corresponding points on them just meet the halving line, move the upper image until it just coincides with the lower one by means of the correction wedge. Read the position of this wedge. Repeat the setting several times and finally adjust the wedge at the mean reading. If possible use two or three known ranges covering the distances the instrument is most liable to be used for, and set the correction wedge at the mean reading for all trials.

The correction lens is inserted in the right telescope so as to bring the images formed by that telescope to a focus in the same plane exactly as those formed by the left telescope. This lens is necessary because of the fact that rays entering the left objective must traverse more glass than those entering the right objective. This tends to bring the former to a focus in a shorter distance. Consequently, a convergent correction lens is inserted in the path of the rays from the right to bring them to a focus more quickly also. It is also used to counterbalance any difference in focal length between the two objective lenses.

The ocular prism consists of a combination of prisms to secure the following effects:

1. To change the direction of the horizontal rays by 90° in the horizontal plane.
2. To reflect these rays upward thru an angle of 50° without changing the natural position of the images.
3. To counteract the reversion produced by each of the objective lenses so that both images will appear natural from right to left.
4. To counteract the inversion produced by the left objective lens but not the right.
5. To divide the field of view into two halves with a distinct horizontal line separating them that will be in the focal plane.
6. To transmit into the lower half of this field of view only rays from the left objective and to the upper half only rays from the right objective.

A prism system to accomplish these results must be somewhat complicated and very delicate of adjustment. It is this part of the optical system that is most likely to become disarranged. An extremely slight displacement of any of the parts due to heating effects or slight strains will vitiate the accuracy of range measurements. The correction wedge affords a means of correcting for minute displacements.

The eye piece is provided with an adjustment for individual correction, and is equipped with a diopter scale.

In addition to the above optical parts, there is a mechanical device, which plays the optical function of enabling the observer so to adjust the two halves of the field that the image of the tip of a church spire in each half will just touch the dividing line. The halving adjuster roller accomplishes this. Its action is merely to raise or lower the right side of the optical tube which is mounted in an eccentric bearing at *B*. The left side of the optical tube is mounted in a gimbal joint at *A*. The effect of this action on the images is to move them both up or down relative to the dividing line in the field of view but at different rates. This adjustment combined with the proper rotation about the axis of the large tube enables the observer to secure a perfect halving of the field of view.

The magnifying power of the telescopes is 15 times, the field of view 3 degrees.

32. SUGGESTIONS AS TO SECURING ACCURATE RESULTS WITH THE RANGE FINDER.

1. The operator must be thoroughly impressed with the sensitivity of the instrument to slight strains and to large errors resulting from poor adjustment or carelessness in effecting coincidence.

2. Never subject instrument to bending strains. Keep hands off tube while making adjustments or measurements.

3. In adjusting instrument:

(a) Do not use sun unless no other means is available, as injurious heating effects may easily vitiate resulting adjustment or even effect a permanent maladjustment. (The moon may of course be used safely).

(b) Use points at known ranges if possible covering the range of distances which it is desired to measure.

(c) Set the measuring wedge range scale at the range of the point used to adjust upon, or at infinity when using the adjusting bar, moon, or sun.

(d) Focus the eye piece very carefully so as to obtain a distinct halving line. This should also be the adjustment for most distinct vision of the object to be observed.

(e) Secure a very accurate halving adjustment. To do this will require adjusting both the line of sight by rotating the whole tube about its horizontal axis and also the halving device by means of the halving adjuster roller.

(f) Bring the corresponding points of the images viewed into coincidence in the center of the field of view. There is a vertical line in the center of the lower half to assist in this.

(g) Readjust the halving.

(h) Readjust the coincidence removing hands from all parts of instrument and tripod while observing.

(i) Note reading of correction wedge scale, to tenths of the smallest division.

(j) Destroy adjustment and repeat complete operation.

(k) Make no less than three adjustments on each point and use the mean of all adjustments as the final setting for the correction wedge.

(l) Frequent large changes in reading of correction wedge scale indicate either a defective instrument or carelessness on the part of those responsible for its care and use.

4. Suggestions (d), (e), (f), (g), (h) and (j) apply equally well to actual measurement of ranges. In so far as time will permit, the mean of several separate adjustments will insure greater accuracy.

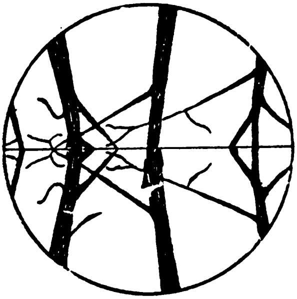


Fig. 28

5. If the objects viewed do not possess distinct points on which to make adjustment, the symmetry of the two images rather than a coincidence should be sought for. Such a case is illustrated in Figure 28.

6. Considerable eye strain may be avoided in the use of this instrument by learning to keep both eyes open while making the adjustments.

The range finder in the hands of a careful intelligent operator thoroughly practiced in the above adjustments will give excellent results. In the hands of a careless operator wilfully or otherwise ignorant of the sensitivity of the instrument he is privileged to use, the range finder is of little, if any, value.

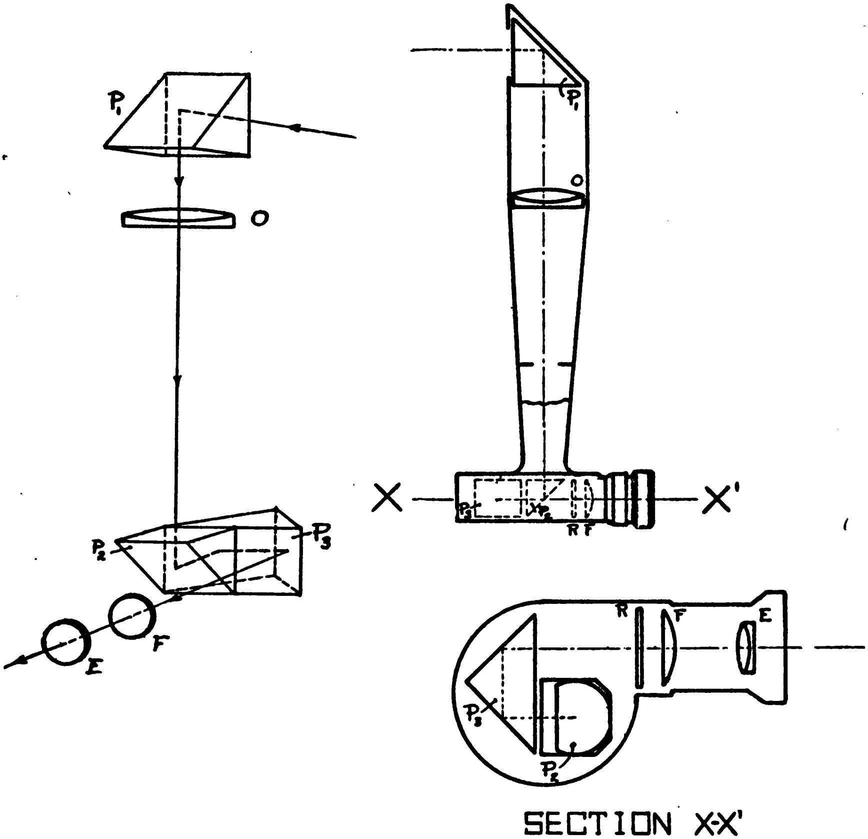
33. OBSERVING INSTRUMENTS.

The Battery Commanders Scissors Telescope and the Signal Corps Type EE Field Glasses are both primarily instruments for observation purposes, although the former is equipped for angular measurements. Both are binoculars—i. e., a telescope is furnished for each eye. The effect of binocular vision (see Par. 27) is somewhat enhanced in both cases as the centers of the objective lenses are farther apart than are the pupils of an individual's eyes. The advantage of this is so small however, as to be doubtful except in the case of the scissors instrument with the telescopes in their horizontal position. Here the rays which finally enter the eye come from points in the objective prisms some twelve times as far apart as the eyes of a normal individual. This produces a distinct effect of depth and aids in determining the relative position in range of objects observed.

34. B. C. SCISSORS TELESCOPE.

Figure 29 shows the optical system of one side of this instrument. The telescope for the other eye is exactly symmetrical. As is readily seen, the optical system differs only slightly from that in the B. C. Telescope, the prisms P_2 and P_3 being interchanged. The combined action of P_1 and P_3 counteracts the inversion, and that of P_3 the reversion produced by the objective lens. R represents the position of the reticule which contains cross lines and mil scales. This is placed in the telescope for the right eye and is of course located in the focal plane of the right objective. Focussing is provided for in the eye pieces only. Each one may be focussed independently.

The lenses and prisms of this instrument are constructed of the best grade of optical glass. Special effort in the design of the lenses has been made to obtain the best definition possible for the whole field of view. The magnification is 10 times, field of view 4° 15′, and the definition such that the field viewed is flat, free from chromatic and spherical aberration, and any distortion. The objective lenses have an aperture of about 1.8 inches, making the emergent beam about 0.18 inches in diameter. This insures good illumination.



SECTION X-X'
ENLARGED

Fig. 29.

35. FIELD GLASSES, TYPE EE.

These binocular glasses are of the prism type of telescope. Figure 30 shows the optical system for the left telescope. O represents the objective lens, an achromatic lens about 1.2 inches in diameter. The eye pieces are of a modified Ramsden type with a field and eye lens so designed as to avoid spherical and chromatic aberration. They are adjusted for each eye and equipped with a diopter scale. The magnification obtained is 6 and the field of view about 7 degrees. The large objective lens and the consequently large emergent pencil, about 0.2 inches in diameter, assure good illumination for all around use. The action of the prism system is fully described in paragraph 19.

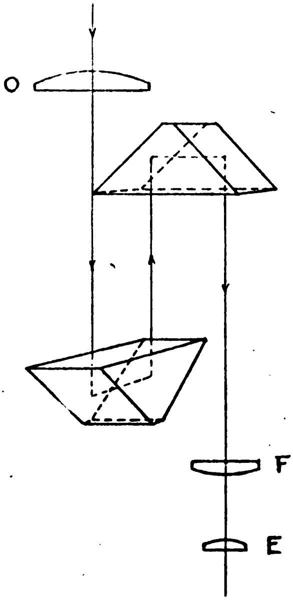


Fig. 30

A reticule containing horizontal and vertical mil scales is fixed in the left eye piece. Some of these reticules also possess a so-called infantry range scale. For field artillery officers this scale is undesirable as it confuses the center and, therefore, the best part of the field of view. Foreign instruments are usually equipped with simple mil scales so designed as to leave the center of the field of view free.

The reticule should be adjusted for the owner's particular interpupillary distance. Unless this is done, the mil scales will not be horizontal and vertical but tilted in the field of view. To make this adjustment, unscrew the eye piece containing the reticule from the body of the instrument. At the inner end of the eye piece is found the reticule retaining ring with a milled end. Unscrew this retaining ring and rotate the mil scale slightly in the desired direction. After a few trials, the correct adjustment should be obtained.

The adjustment of the prisms is delicate and they should not be removed for cleaning or any other purpose by anyone who is unfamiliar with optical adjustments.

36 SUGGESTIONS AS TO THE PROPER AND EFFICIENT USE OF OBSERVING INSTRUMENTS.

The Instrument. Proper focussing is of primary importance. Improper focussing will soon cause eye fatigue and will always lead to uncertain observation. The following procedure should be adopted in focussing all telescopic instruments equipped with the adjustments mentioned.

(a) Adjust for interpupillary distance if using binoculars. This means simply to have the centers of the eye lenses at the same distance from each other as the pupils of the eyes. It may be done by looking thru the instrument at the sky or clouds. Do not strain the eyes. If the interpupillary distance is not correct, two circles (the apertures of the objective lenses) will be seen mostly overlapped but not entirely coincident. Change the interpupillary distance until these circles coincide exactly—i. e. are exactly superposed without any strain on the eye. To insure relaxation of the eyes, look at a distant object without the instrument a moment and then look thru the instrument. If properly adjusted only a single perfect circle will be seen.

(b) Focus the eye piece on the reticule or cross hairs. To do this, also look thru the instrument at the sky, and turn the eye piece in and out until that position is found where the cross hairs are most distinct. This position will be quite definite and will differ for different eyes depending of course upon their distance of distinct vision. Rest the eyes occasionally either by closing them or looking at objects 100 yards away or more. In binoculars, the reticule is found only in one telescope and the eye piece of that telescope is adjusted first.

(c) If the instrument is not provided with adjustment for the objective lens, any object viewed should appear perfectly distinct thru the eye piece that has been adjusted, atmospheric conditions permitting. Furthermore, if the adjustment is perfect, the lines of the reticule and the image of the object viewed should coincide exactly. To test this, move the head slightly from side to side. If they are exactly coincident they will move together; the lines of the reticule will not move relative to the image of the object viewed. If this is true the eye-piece is perfectly focussed.

(d) For binoculars, the other eyepiece should now be focussed. To do this look thru that eye piece at an object and move it until the object appears most distinctly. Look for the edges and details of the object in this adjustment but do not strain the eye. The instrument should now be in perfect adjustment for both eyes. .Note the diopter readings for each eye piece.

(e) For instruments like the B. C. telescope which have an adjustment for the objective lens also, first focus the eye piece as in (b). Then turn the instrument on the object to be observed and move the objective lens until the detail of the object viewed and the cross-hairs are both equally distinct. If this is correctly done, there will be no parallax between the lines of the reticule and the image of the object viewed—i. e. there will be no relative motion between the two when the eye is moved slightly from left to right.

The Eye. Eye strain when not due to improper focussing may be due to any of the following causes:

(a) Straining the eye to see more detail than is present or than the eye itself can resolve. Remember that the eye should be under no greater strain than when reading print at the distance of distinct vision.

(b) Movement of the instrument causing rapid movement of the image which the eye tries to follow. Heat waves produce a similar effect. Hold glasses steady always with both hands, elbows against body to give support. For instruments of magnification greater than eight times some firmer support should be provided when possible.

(c) Prolonged use. Rest the eyes occasionally whenever time permits by either looking at distant objects without instrument or by closing them.

Whenever an instrument is to be used in prolonged, continuous observation for which the maximum definition is not necessary, there is another way of focussing the eye piece which avoids a great deal of eye strain. This adjustment is such that the rays entering the eye are parallel—i. e., the image of the cross hairs of the reticule is at infinity or a great distance and the eye therefore is in a relaxed condition (see par. 22). To accomplish this adjustment requires a little practice. As before, look thru the instrument at the sky. In bringing the cross hairs into focus, however, the eye must be accomodated for distant objects. Look at a distant object and then thru the eye piece, adjusting the latter so that the cross hairs appear distinct immediately upon transferring the eye from the distant object to them. To test your success at this adjustment look at a printed page and then into the eyepiece. The cross hairs should appear out of focus at first but will gradually come into focus as the eye relaxes. When using this adjustment for binocular instruments both eye pieces must be looked thru simultaneously when adjusting the second one and the combined image and the cross hairs brought to the same focus. It must be remembered that this adjustment does not give maximum definition but will give minimum eye strain for continuous observation.

37. DEFECTIVE VISION AND OBSERVING INSTRUMENTS.

Neither shortsightedness nor farsightedness interferes with the efficient use of telescopes equipped with adjustable eye pieces unless the defect in vision is too pronounced. Eye-glasses should be discarded so that the pupil of the eye may be placed as near as possible to the eye piece. If this is not done, the observer will experience poorer illumination and a smaller field of view.

Astigmatism on the other hand cannot be corrected for in the instrument. If the defect is so pronounced that some correction is necessary, it is recommended that the individual have very small (same diameter as eye lens) cylindrical lenses set in a rubber cell which can be snapped on the eye guards of his field glasses. In this way proper correcting lenses can be permanently attached to field glasses and placed so near the eye lenses that they do not reduce the efficiency of the instrument to any great degree. Any first class optician should be able to do this. Be sure, however, that some mark is made to indicate when the axis of the lens is turned to its proper position. Also the same care should be taken of the surfaces of these lenses as those of the instrument itself.

If it is impossible to secure the above device, officers having astigmatism will be forced to wear their spectacles to secure maximum definition. In order to place the eyes as near as possible to the eye lenses, it is best to remove the eye guards (or cups). This will, however, impair the illumination by allowing considerable stray light to enter the eye from around the edges of the eye piece. To prevent this, either shade the eyes with the hands ,or better, provide some kind of black leather, cloth, or rubber, screen which can be permanently attached to the eye pieces.

APPENDIX A.

1. THE FRENCH SIGHT.

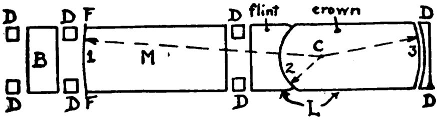


Fig. 31.

This is a very clever and interesting instrument. Figure 31 shows its optical construction. *B* represents a block of glass with ground surfaces. *M* is a glass mounting. One of its surfaces *FF*, is spherical and coincides with the focal plane of the lens, *L*. This surface is not polished but of ground glass and is blackened, save for two thin perpendicular lines in the form of a cross. These two lines illuminated by the light coming through B, constitute the object looked at thru the lens, *L*. They are the cross hairs of the instrument. The lens, *L*, is a compound achromatic lens. Its surfaces 2 and 3 are spherical and have a common center, C, which is also the center of the surface *FF*, or 1. Since the lines on *FF* are at a distance from *L* equal to the focal length of the latter, rays coming from single points on them and passing thru *L* emerge parallel to each other. Consequently, the points from which they come, or the image of the lines, appears to be at infinity. Thus the eye of a gunner looking at these cross hairs must be relaxed or focussed on a distant object in order to see them clearly. In other words, the gunner looking along the top of the sight can use a distant object as an aiming point and alternately looking above and thru the sight can see both the aiming point and the cross hairs distinctly without any change in the accomodation of his eye. This is true no matter how far his eye is from the sight since the image of the cross lines is so far away. The surface *FF* is curved, not plane, in order to counteract the distortion and curvature of the image that would result from the spherical aberration due to the lens, *L*. The image obtained is remarkably flat, straight and sharp.

Several diaphragms, marked *D*, are used to hold the glass parts in place. These diaphragms and lenses are all sheathed in black paper which in turn is surrounded by a strong brass envelope.

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